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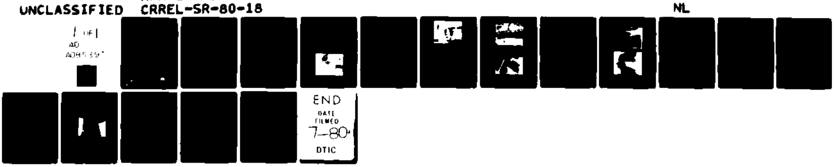

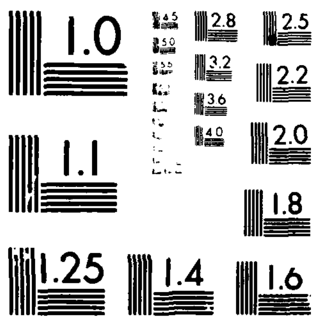

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B. Hanamoto, J.J. Gagnon and B. Pratt

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U.S. ARMY SATELLITE COMMUNICATION AGENCY

UNITED STATES ARMY
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Ice buildup on communication antenna dishes begins to cause signal reception problems when the thickness exceeds 0.64 cm (0.25 in.). CRREL's copolymer coating, which reduces the adhesive force between ice and the coated surface, was tested on antenna dish panels to facilitate ice removal. A combination of the copolymer coating and heat proved to be an effective method of removing ice from the panel.

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PREFACE

This report was prepared by Ben Hanamoto, Research General Engineer, and John J. Gagnon, Engineering Aide, Ice Engineering Research Branch; and Blanchard Pratt, Electronics Engineer, Engineering and Measurement Services Branch, U.S. Army Cold Regions Research and Engineering Laboratory. The work was carried out under U.S. Army Satellite Communication Agency Order No. SA 425. The report was reviewed by Dr. George D. Ashton and Stephen Ackley of CRREL.

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DEICING A SATELLITE COMMUNICATION ANTENNA

by

B. Hanamoto, J.J. Gagnon and B. Pratt

INTRODUCTION

The need for around-the-clock operations by satellite communication antennae puts additional demands on those units located in cold regions. The antennae without protective dome coverings experience icing problems on the reflective parabolic dish. One of the trouble spots is Omaha, Nebraska (Fig. 1).

The agency responsible for the operation of the antenna, the U.S. Army Satellite Communication Agency (USASATCOMA), contacted CRREL to ask for help in solving the icing problem. Signal reception is interfered with when the ice coating on the antenna dish exceeds 0.64 cm (0.25 in.). Signal attenuations of 5-15 decibels (dB) had been observed because of ice buildup. The task was either to prevent ice formation or to remove the ice so that signal reception would not be interrupted.

Ice formation could be prevented by a protective cover over the antenna unit or by heat. If prevention is not possible, removal of ice after formation is the other alternative. CRREL can address the second option. Researchers have been trying, for the past several years, to develop a chemical coating that reduces the adhesive force between ice and the coated surface, making ice removal easier.

Figure 1. Satellite communication antenna, Omaha, Nebraska.

The chemical coating was developed to remove built-up ice from navigation lock walls. The buildup of ice on the walls of narrow locks hinders the passage of wide vessels during the winter navigation season. The most successful compound of the many tested was a long chain copolymer made up of polycarbonates and polysiloxanes. The most effective coating was a solution of the copolymer, silicone oil, and toluene. When sprayed or brushed onto a cleaned surface, a thin layer of the solution is deposited after drying. The coating does not prevent the formation of ice, but does reduce the adhesive strength between the coated surface and the ice. This strength reduction on an aluminum surface was: uncoated, 35.11 N/cm^2 (3.58 kgf/cm^2); coated, 0.05 N/cm^2 (0.005 kgf/cm^2). On smooth concrete, the reduction was: uncoated, 74.14 N/cm^2 (7.56 kgf/cm^2); coated, 1.31 N/cm^2 (0.134 kgf/cm^2). These tests were conducted at -2°C. The effort needed to remove ice will be reduced considerably on these coated surfaces. Both heat and vibration have been used successfully in removing ice from coated concrete lock walls.

SCOPE OF WORK

The task was to devise a way to remove ice from the antenna dish so that signal reception would not be interrupted or attenuated. The Ice Engineering Facility at CRREL provided an ideal site for testing the various ways of removing ice. A coldroom was available where temperatures in the troublesome range of -3°C to 0°C could be maintained within ± 1°C. Enough copolymer solution was also available to coat three panel sections of an antenna reflector dish. Four panels were obtained from USASATCOMA, Fort Monmouth, New Jersey. The panels were from the innermost section of the parabolic dish, curved trapezoids measuring 30.5 x 114.3 x 216.6 cm. All panels were painted with the highly reflective paint used on the dishes now in service.

Three of the panels were coated with the copolymer, while one was left untreated and used as a control. One coated panel was used in tests to determine the effects of the copolymer film on signal reception and attenuation.

Two methods of removing ice from the panels were tried: heat and vibration. Heat was applied to the panels by attaching commercially available heating tapes to the back of the panels. Preliminary tests determined the optimum spacing for the cables, and all three panels used in the deicing tests were heated identically. Vibrations were applied to the panels with a variable frequency vibrator. Preliminary tests were conducted on the panels and mounting fixtures to determine the resonant frequency and maximum acceleration condition of the system.

The ice buildup procedures for all tests were identical and the minimum thickness of the ice sheet was 0.64 cm. During the tests, the panels were oriented between 10° to 34°, the operating elevation of the dishes.

Figure 2. Copolymer application.

TEST PROCEDURE

Panel Preparation

The three test panels had small scratches where paint had been removed. The panels were first wiped down with toluene to clean them, then the scratches were painted with a brush.

The panels were wiped down once more before being coated with the copolymer. Two types of the copolymer (General Electric LR5630 and GR5530) were applied to three of the panels and were designated sample A and sample B respectively. One entire panel was coated with LR5630, one with GR5530. The third panel was coated with both LR5630 and GR5530; the top half with one, the bottom half with the other. The copolymer was applied with a brush, starting at the top and making sure that the brush strokes were with the length of the panel (Fig. 2). The third panel was used for radio wave analysis of the copolymer.

Another phase of the panel preparation was to determine an efficient way of placing the heat tape. One panel was wired with two types of heat tapes with various spacings. One of the heat tapes had a circular cross section and a power output of 26.3 W/m; the other heat tape had a cross section similar to a dumbbell and delivered 23.0 W/m. The first heat tape was attached to the back side of the panel with RTV (silicone rubber cement); various spacings were tried. The heat tape was run the length of the panel in an "S" pattern. The spacings were 5.1, 7.6, 10.2, 12.7 and 15.2 cm. Thermocouples were temporarily attached to the other side of the panel in the center of the spacings. The leads were

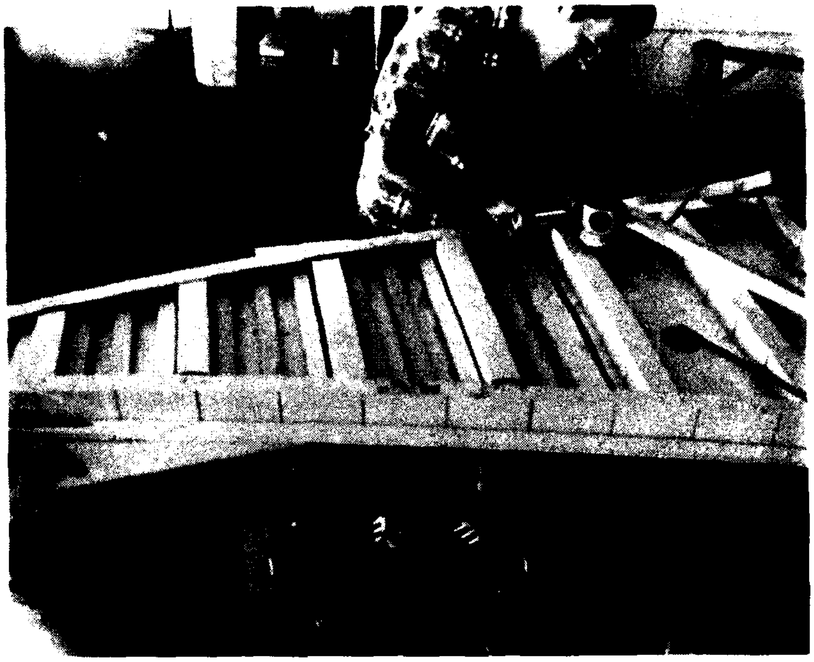

Figure 3. Installation of the heating cable and cable insulation.

Figure 4. Icing of the panel, spray gun application of water.

then connected to a 10-channel, digital thermometer and the panel placed in a coldroom at approximately -2°C. The heat tape was plugged in and time and temperature changes were recorded. This test was run for at least 20 minutes. The panel was then allowed to cool and the test was repeated (a minimum of three runs of each test).

The thermocouples were then moved to the location of the second type of heat tape and attached in the center of the spacing. After testing the second heat tape, the panel was iced up using a squirt bottle (similar to window cleaner bottles found in the home). The water was warm, 50°C, to keep the bottle from icing. The room temperature was -11.3°C.

After the ice was approximately 0.64 cm thick, the room was warmed to -2.5°C and both heat tapes were plugged in. The phase change and the melt pattern were easily observed. It was also evident that ice on the edges of the panel was not melting.

Heat tape was applied to the edges of the panel and thermocouples were attached to measure the exact temperature.

The heat tape was then removed. The RTV (silicone rubber cement) was a very good adhesive but had poor heat conductance. After testing other adhesives, it was decided that Armstrong 520 would be better, and it was applied according to manufacturer's specifications. It was also decided that insulation on the back side of the panel would improve the effectiveness of the heat tape (Fig. 3). Spray foam insulation was tested because of ease of application, but Styrofoam strips were eventually chosen for the deicing tests.

A series of tests revealed that it was best to create ice using water with a temperature less than +2°C, and a room temperature of approximately -6°C. With a room to water temperature difference greater than 15°C, cracking and lifting of the ice occurred. This resulted in less than 100% adherence of ice to the panel. Two sprayers were used: a squirt bottle and a compressed air paint spray gun. The squirt bottle was used first to prevent the copolymer surface from being contaminated with oil from the compressor. After the surface was covered using the squirt bottle, the paint spray gun was used to build the 0.64-cm thickness (Fig. 4).

Heat was tested as a deicer in the coldroom at temperatures between -2.5° and -1.7°C. The time of heat application was measured and a visual monitor of all effects was kept and noted. The end of a test was signified by the disappearance of ice from the panel. The three experimental panels were tested simultaneously.

The vibration tests were conducted individually on each panel (Fig. 5). All three panels were iced simultaneously and remained in the coldroom at temperatures between -2.5° and -1.7°C. Again time was measured and a visual monitor of all effects was kept and recorded. Finally, a test series which combined heat and vibration was conducted with the same measurements and visual notes recorded.

Figure 5. Panel vibration set-up.

Figure 6. Panel temperature measurements with thermocouples.

TEST RESULTS

Preliminary tests were conducted to try to optimize the heating cable spacing so that the minimum length of cable would provide the maximum heat to the panel. Cable spacings were varied from 5.1 to 15.2 cm.

The stiffener box section on the back of the panel required extra attention. It was thought that the added thickness of the box section flange might affect heat conduction to the panel, so tests were run with the cable on the flange as well as adjacent to it. The outside dimension of the box section was 6.4 cm, 10.2 cm including the flange. Temperatures were measured midway between the heat cables on the front side of the panels (Fig. 6). Copper-constantan thermocouples were placed at these locations and temperature vs time recordings were taken. Equivalent heating effects were obtained whether the cable was next to the box section or at the flange. Almost equivalent heating was also obtained whether the cables were 5.1 or 10.2 cm apart on the flat section of the panels between the box stiffeners. Heat tapes with outputs of 23.0 and 26.3 W/m also showed little difference in heating the panel. Time vs temperature plots for the various setups are shown in Figures 7-10.

The optimum cable arrangement was found to be placing cables along each flange of the box sections with one line midway between, a distance

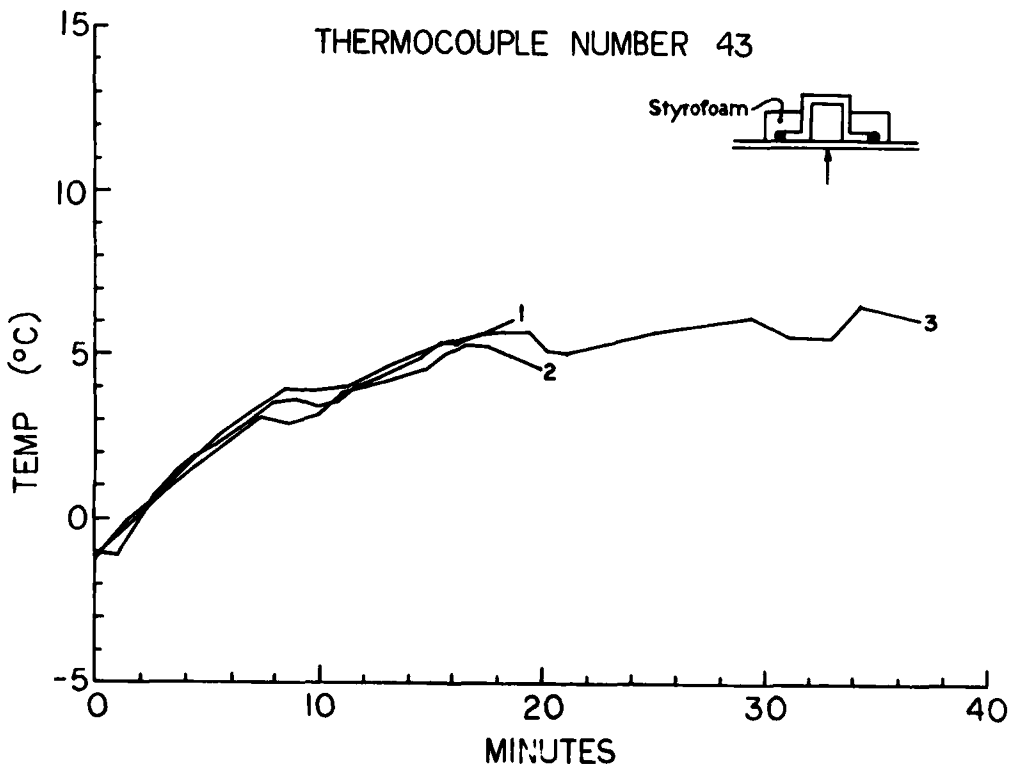

Figure 7. Time vs temperature, box section, 10.2-cm spacing.

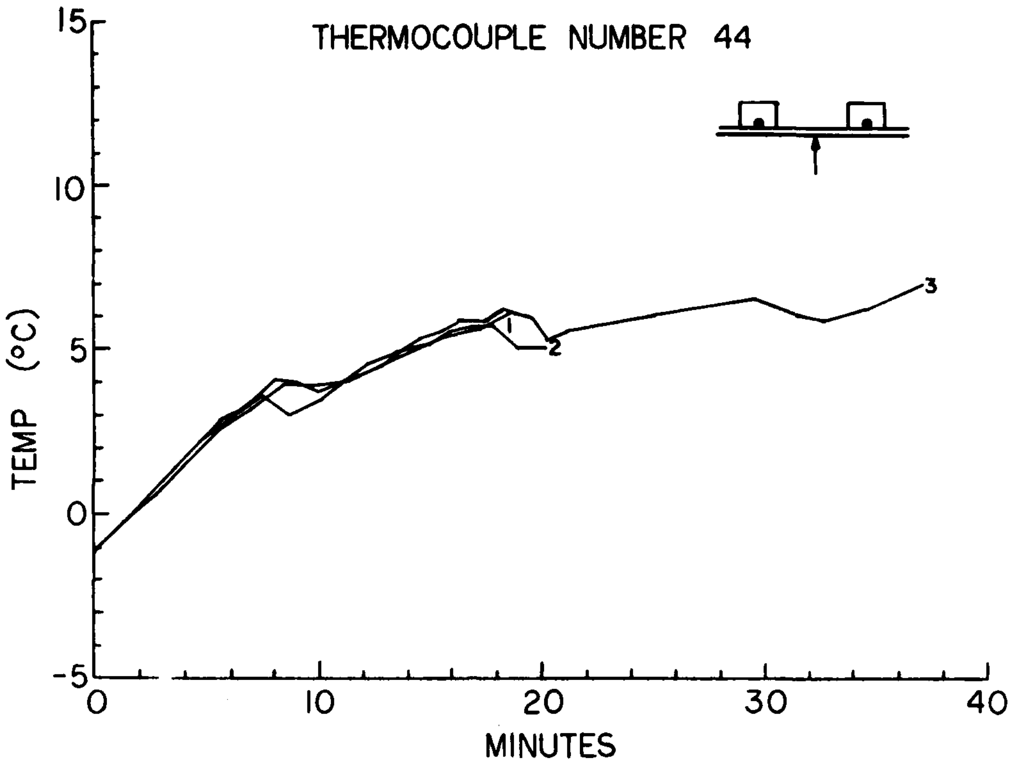

Figure 8. Time vs. temperature, 10.2-cm heat cable spacing.

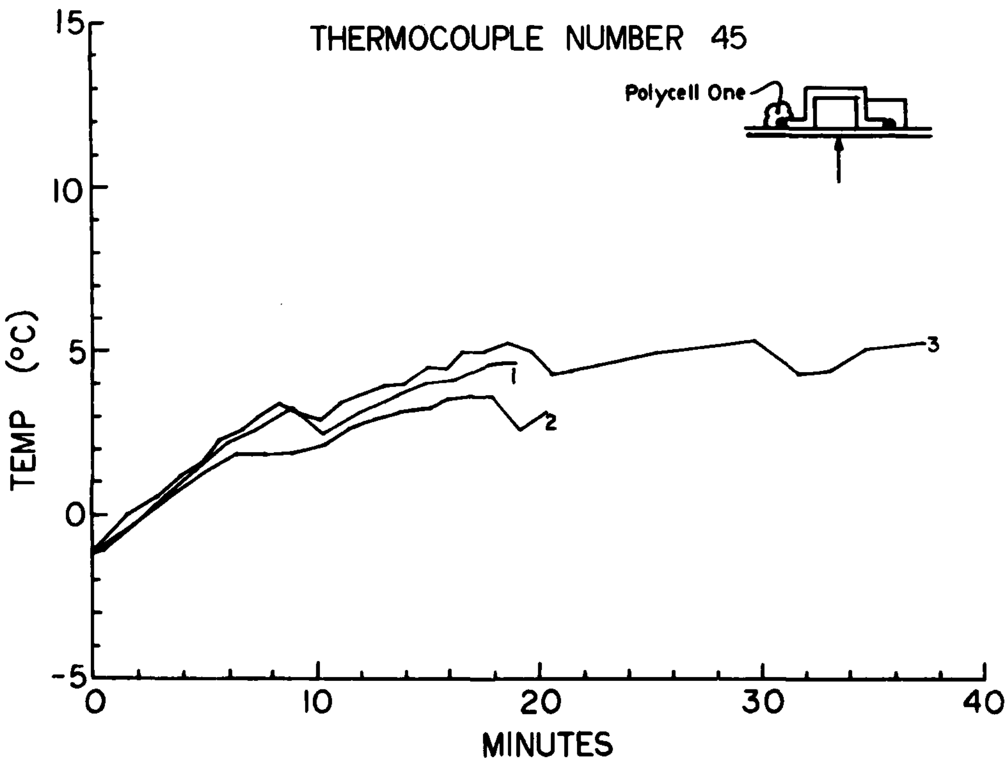

Figure 9. Time vs. temperature, varying insulating materials.

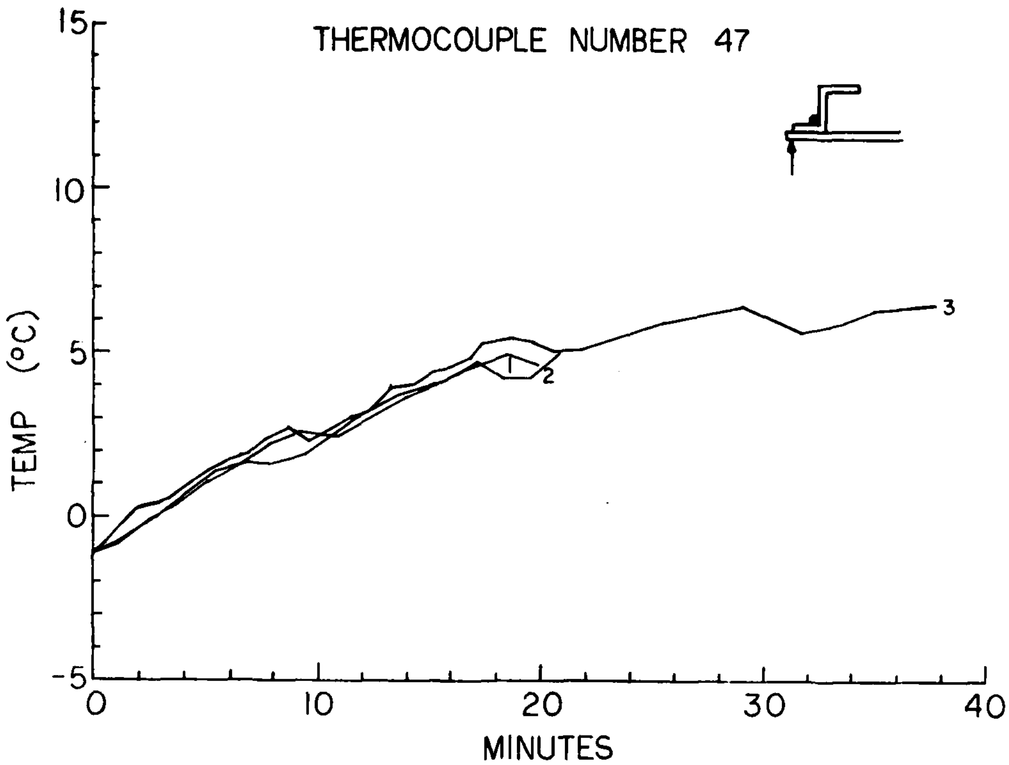

Figure 10. Time vs temperature, panel edge.

of 9.5 cm between cables. At each box section, the distance between cables was 10.2 cm. Heat cables with an output of 23.0 W/m were used and were insulated with a 3.8 by 3.8 cm Styrofoam strip to maximize heat input toward the panel.

Deicing Tests

The deicing tests using heat were conducted at temperatures between -2.5° and -1.1°C. After the 0.64-cm ice sheet had been built up on the panels, all three heating cables were plugged in. Time of melting and heat effects on the ice sheet were recorded. Melt lines beneath the ice sheet were visible on the coated panels after about 5 minutes. Melt lines on the standard panel appeared after 7 minutes. The first drops of water off the panels were observed after about 14 minutes and melt lines continued to appear along all heat cable locations afterwards (Fig. 11). On copolymer panel A, the intact ice sheet slid off after 19, 21 and 24 minutes. The entire ice sheet slid off copolymer panel B after 20, 22 and 24 minutes. The ice sheet on the standard panel continued only to melt with little or no sliding. After 90, 125 and 125 minutes, the standard panel was clear of ice (a variation in ice thickness accounts for the one shorter time). Table 1 below shows the recorded test results.

Table 1. Deicing test results.

Test no. 2: Room temp. -2.8° to 1.7°C; panel elv. 30°

Time	Panel A (0.64 cm ice)	Panel B (0.64 cm ice)	Std. panel (0.35 cm ice)
1145	Heat on	Heat on	Heat on
1150	Melt lines appear	Melt lines appear	
1204	Ice off		
1205		Ice off	
1233			25% melted
1245			50% melted
1252			75% melted
1303			90% melted
1315			Ice free

Test no. 3: Room temp. -2.5 to -1.1°C; panel elv. 30°

Time	Panel A (0.64 cm ice)	Panel B (0.64 cm ice)	Std. panel (0.64 cm ice)
1255	Heat on	Heat on	Heat on
1259	Melt lines appear		
1301		Melt lines appear	
1302			Melt lines appear
1309		First drip	First drip
1310	First drip		
1316	Ice off		
1317		Ice off	
1334			1.3-cm slide of sheet
1355			Edges melted through
1403			4.5-cm slide of sheet
1405			10% melted, top & edges
1435			Midpanel, ice melted through
1436			35% melted
1455			Bottom piece dropped off
1510			90% melted
1520			Ice free

Test no. 4: Room temp. -2.5° to 1.1°C; panel elv. 30°

Time	Panel A (0.64 cm ice)	Panel B (0.64 cm ice)	Std. panel (0.64 cm ice)
1200	Heat on	Heat on	Heat on
1225	Melt lines appear		
1226		Melt lines appear	
1227			Melt lines appear
1232			First drip
1234	First drip		
1235		First drip	
1244	Ice off	Ice off	

TABLE 1. (cont'd)

1307	0.6-cm slide of ice sheet. Edges melted.
1318	1.3-cm slide of ice sheet. 10% melted
1353	50% melted. Melted through at heat tape line near bottom
1404	80% melted
1418	95% melted
1425	Ice free

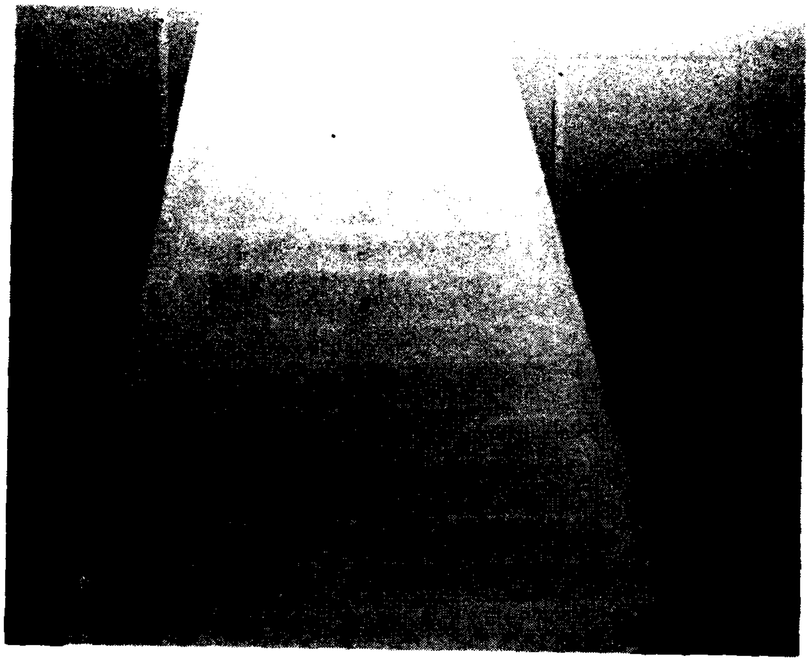

Figure 11. Melt lines, heating cable.

Radio Wave Analysis of the Copolymer

The effect of the copolymer coatings on the radio-frequency characteristics of a microwave dish antenna was also tested. The testing was done in two phases:

1. A comparison of the attenuation of a radio-frequency signal reflected from the surface of a test panel, with and without the coating.

2. A comparison of the voltage standing-wave ratio (VSWR) in a wave-guide transmission line terminated in a short circuit, with and without the coating applied to the inner surface of the short-circuit plug.

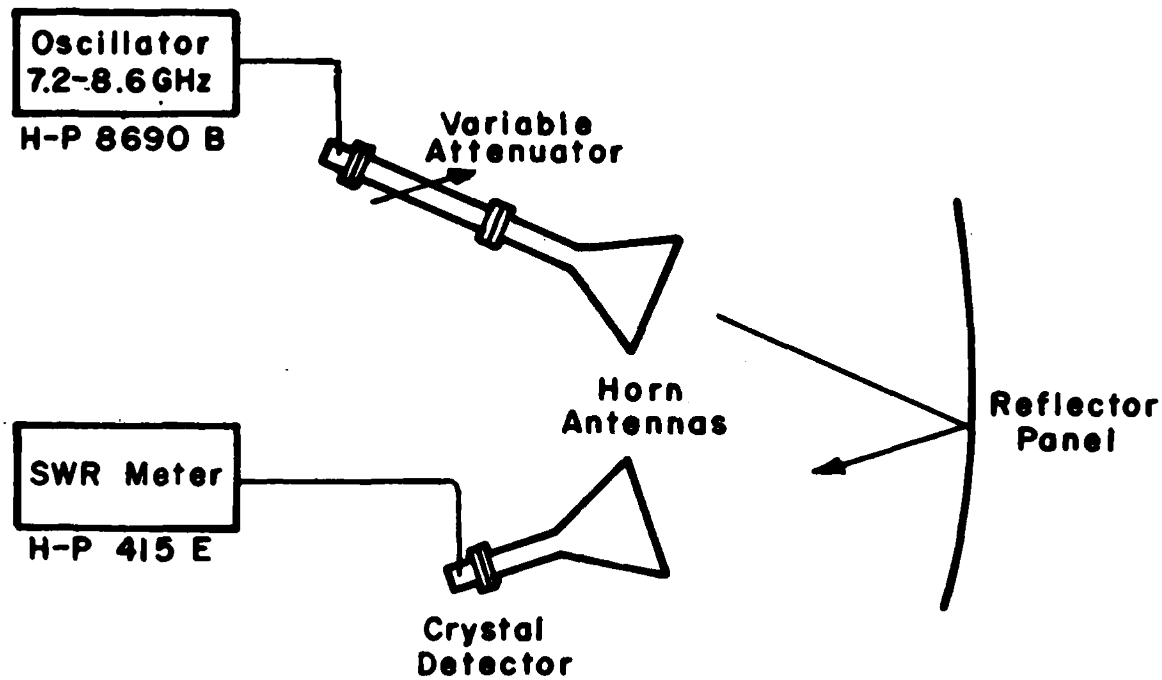

Figure 12. Reflector test setup.

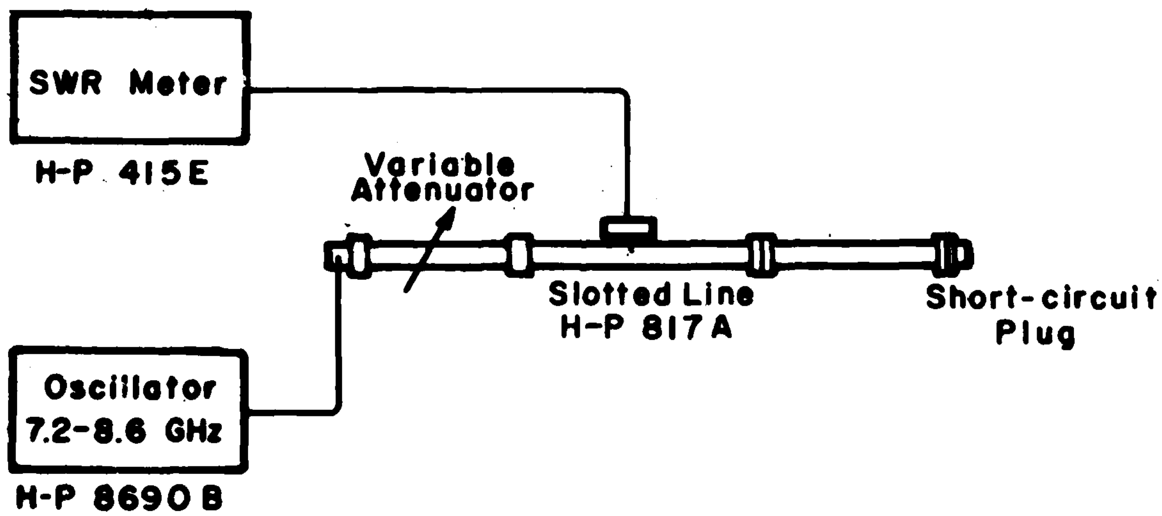

Figure 13. VSWR test setup.

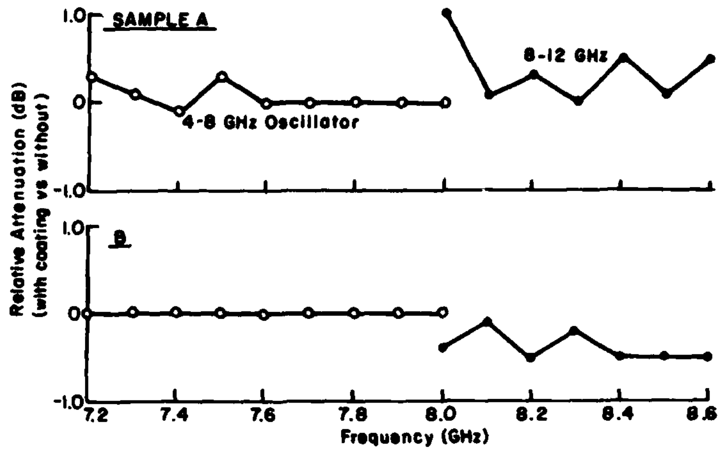

Figure 14. Relative attenuation of reflected signal.

The frequency-range of interest is 7.2 to 8.6 GHz. The radio-frequency source used in the tests was a Hewlett-Packard 8690B microwave oscillator. It was necessary to change the plug-in oscillator section when going through 8.0 GHz. This has caused repeatability problems when taking data above 8.0 GHz during the phase I test. Figures 12 and 13 show the equipment setup for each test phase. Two samples of the coating were tested. These were designated as sample A and B.

In phase I of the tests, a radio-frequency signal was directed toward the test panel. The strength of the reflected signal was measured with a Hewlett-Packard 415E SWR meter which reads attenuation in decibels (dB). Figure 14 shows the difference in measured attenuation encountered in each of the two samples after the coating was applied. For the range from 7.2 to 8.0 GHz, there was no change due to the coating with sample B and a slight increase with sample A. As mentioned previously, it was necessary to change the oscillator plug-in to cover the range 8.0 to 8.6 GHz. Each time this was done there were small changes in the signal level due to the mating of connectors in the plug-in. This affects the measurements above 8.0 GHz. Without taking this into account, there was an apparent loss above 8.0 GHz due to sample A and an apparent gain due to sample B.

In phase II, the VSWR of a short-circuited waveguide was measured, first without any coating applied to the short-circuit plug and then with each sample of coating. Under ideal conditions, the VSWR on a short-circuited transmission line will be infinite. In practice, one obtains a VSWR of 50 or 100 to 1 because of losses. If a loss-producing material is inserted into the waveguide, the VSWR will be further reduced. In these tests, the VSWR was between 50 and 250 to 1 and was unchanged by introducing the coatings.

Vibration Tests

Another goal of the tests was to determine the effects of vibration on an ice-covered panel. Both the copolymer coated and standard uncoated panels were tested using a Ling Dynamic Systems 411 Series Shaker, with an auxiliary amplifier and signal generator. The panel and test fixture reached a resonant condition at 64 Hz and by varying the gain of the amplifier, a maximum g value of 30 g was measured at the shaker output. The maximum displacement was 0.88 cm (0.35 in.) with a sine wave input. The panel was attached to the shaker by a rigid, 1.27-cm (0.5-in.) diameter rod. Continual vibrating for almost 2 hours produced no effects on the ice sheet, either on the coated or standard panel. This is equivalent to the time required to melt the ice off the standard uncoated panel. While vibrating the panel, the heat cable was plugged in and the time required for the ice sheet to slide off was the same as with heat alone.

The orientation of the shaker to the panel was changed so that the vibrating force was perpendicular to the panel. This produced no change. Vibrating frequencies were changed to 32 and 96 Hz with no change in results. Hand impact tests with a 0.45-kgf (1-lbf) hammer produced no effects other than fracture lines in the ice at the impact points.

CONCLUSIONS

Two methods of removing ice from antenna reflector panels were tried: vibration and heat. Both a standard panel currently in service and panels coated with a copolymer film which reduced ice adhesion forces were tested. Heat and vibration were applied to both types of panels. Vibration does not appear to help in ice removal; however, heat will remove the ice cover from the panels. On copolymer coated panels, the intact ice sheet slid off in a little over 20 minutes. It required over 2 hours to remove the ice from the uncoated panel by melting the ice. The 1.58-m^2 (17.0-ft^2) copolymer coated panel required a power input of 483 W and an energy requirement of 177 Wh to remove the ice. If the troublesome lower 90° sector of the antenna dish were to be heated, an area about 75 m^2 (806 ft^2), the power requirement would be about 22.9 kW and 915 m (3,000 ft) of heat cable would be needed. Coating the 90° sector with three coats of the copolymer solution would require 37.9 l (10 gal.). The test results indicate that a combination of the copolymer coating with the application of heat to a reflector antenna dish will remove ice within a reasonable time.

When a thin dielectric coating is applied to a conducting reflector surface, one should expect the loss to be negligible, even if the dielectric material itself has appreciable losses at microwave frequencies. This is true because the electric field is zero at the surface. The results of the tests on the short-circuited waveguide support this premise. The results of the tests using the copolymer coated reflector panel support the general idea that the losses are small, but outside influences, such as reflections from objects other than the panel and the effects of varying contact losses as oscillator plug-in modules are changed, preclude accurate interpretation.

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